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Address delivered by the President, J. C. Adams, Esq., M.A., Fellow and Tutor of St. John's College, Cambridge, on presenting the Gold Medal of the Society to M. Peters.

It has already been announced to you that the medal of the Society has been awarded to M. Peters, for his two papers, entitled, "Numerus Constans Nutationis ex Ascensionibus Rectis Stellæ Polaris in Specula Dorpatensi Annis 1822 ad 1838 observatis deductus," and "Recherches sur la Parallaxe des Etoiles Fixes," which are published respectively in the third and fifth volumes of the sixth series of the *Mathematical and Physical Transactions of the Imperial Academy of Sciences of St. Petersburg*; and it is now my duty to explain to you the grounds of this award, which (unless their effect be marred by my very imperfect statement of them) will, I doubt not, secure your approval.

These papers form part of a series emanating from the astronomers of the Pulkowa Observatory, and having for their object the advancement of sidereal astronomy; first, by a new and more accurate determination of the elements which affect the apparent places of all the stars, such as precession, nutation, and aberration, and, secondly, by an examination of the peculiarities affecting individual stars, such as annual parallax and proper motion, by which alone we can gain a knowledge of the scale on which the visible universe is constructed, and of the arrangement in space and of the relative motions of the bodies of which it is composed.

These important objects have been steadily pursued at the Pulkowa Observatory, under the guiding mind of its illustrious director, with an energy and success which have placed that establishment in a position with respect to sidereal astronomy, similar to that which our own observatory of Greenwich occupies with respect to the observation of the moon.

The order of date, as well as the nature of the subjects treated of, leads me first to speak of M. Peters' paper on the constant of nutation. But before proceeding to give an account of the paper itself, it may not be out of place to advert rapidly to former researches respecting nutation.

When Newton traced the precession of the equinoxes to its cause in the attraction of the sun and moon on the protuberant equatoreal zone of the terrestrial spheroid, he perceived that the sun's action would likewise cause a nutation of the earth's axis, the period of which is half a year. He contents himself with remarking that this nutation can be scarcely sensible.

In the same way, of course, the moon's action produces a small nutation of which the period is half a month. Abstracting these nutations, the tendency of the sun's action is to make the pole of the equator move in a circular arc about the pole of the ecliptic;

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and in a similar manner the moon's action tends to make the pole of the equator describe a circular arc about the pole of the moon's orbit for the time being. Now, as this latter pole moves in a circle about the pole of the ecliptic in a period of about nineteen years, it is easy to see that this will give rise to an inequality in the rate of precession, and to a change of the obliquity of the ecliptic, having the same period.

It is curious, however, that Newton does not allude at all to this, which constitutes by far the most important part of nutation; and this is the more remarkable, since the principles which he lays down in treating of precession are quite sufficient to obtain, by means of very simple geometrical reasoning, not only the law, but, very approximately, the coefficients of the inequalities in the precession and obliquity due to this cause.

The state of practical astronomy, however, in Newton's time, was not sufficiently advanced to induce him to enter more fully into this subject; and it was, consequently, reserved for the immortal discoverer of aberration to detect these motions of the earth's axis by means of his observations, and then to trace them to their true cause. While discussing the observations which led him to the discovery of aberration, Bradley noticed that the annual changes of declination of the stars did not exactly correspond with those which would be occasioned by precession, and he made allowance for this by employing in the reduction of his observations the changes deduced from the observations themselves.

No sooner, therefore, had Bradley determined the law and the cause of aberration, than a new subject of investigation presented itself, requiring a much longer course of observations for its complete examination. Comparing his observations of different stars, he found that their changes of declination were such as might be attributed to a real motion of the earth's axis, and he was not slow in perceiving that the varying action of the moon upon the equatoreal parts of the earth, according to the different positions of the nodes of the lunar orbit, was the probable cause of this motion. During the course of the observations, Bradley communicated what he had observed to Machin, who was then "employed in considering the theory of gravity and its consequences with regard to the celestial motions," mentioning at the same time what he suspected to be the cause of these phenomena.

Machin confirmed this supposition, and showed that the observed motions might be very nearly accounted for, by supposing that the pole of the equator described a small circle about its mean position as centre, during a period of the moon's nodes.

Bradley remarked that his observations would be more completely represented by supposing the true pole to move about the mean pole in an ellipse instead of in a circle, the major axis being in the solstitial colure; and this conclusion is perfectly true, the minor axis being, however, a little smaller than he made it.

Bradley continued the observations during an entire revolution of the moon's nodes, and then published an account of his discovery

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in the *Philosophical Transactions for* 1748, in a paper which is a perfect model of lucid statement and strict inductive reasoning.

In the following year, D'Alembert succeeded in determining the true motion of the earth's axis by means of analysis, in his "Recherches sur la Précession des Equinoxes et sur la Nutation de l'Axe de la Terre," and since that time the subject has been repeatedly treated of by physical astronomers. The most complete and elegant theoretical investigation, however, of the motion of the earth about its centre of gravity is that given by Poisson in the seventh volume of the *Mémoires de l'Institut.* The theoretical investigations with respect to nutation leave nothing to be determined by observation, except the value of one constant. This is generally chosen to be the coefficient of the principal inequality in the obliquity of the ecliptic. The accurate determination of this constant is important, not only from its being required for the reduction of star observations, but also from its affording one of the best means we have of determining the mass of the moon.

In precession we see the effect of the joint action of the sun and moon, but by means of the observed quantity of nutation, we can ascertain what part of this is due to the moon's action, and having thus obtained the ratio between the actions of the sun and moon, the moon's mass easily follows.

The most trustworthy determinations of the constant of nutation, previous to this of M. Peters, are those of MM. Von Lindenau, Brinkley, Robinson, and Busch; and M. Peters begins his memoir with a critical examination of their labours.

The results of the three latter astronomers present an admirable agreement, while that of Von Lindenau differs from them by about a quarter of a second. Von Lindenau employed about 800 observations of right ascension of *Polaris,* made at different observatories, and therefore his result is liable to be vitiated by the different personal equations of the several observers. We shall find in the sequel that this remark is important.

Brinkley deduced his value of the constant from 1618 observations of ten stars made about the times of two opposite maxima of nutation in declination with the Dublin meridian circle, the proper motions of the stars being determined by the comparison of his own declinations with those in the *Fundamenta.* As these observations embrace only half a period of the moon's nodes, the result is liable to be affected by errors in the supposed proper motions.

Dr. Robinson's investigation is contained in the eleventh volume of the *Memoirs* of the Royal Astronomical Society. He employs the declinations of the polar star, and of fourteen others observed at Greenwich between the years 1812 and 1835 with Troughton's mural circle. There can be no doubt of the high value of this investigation, but M. Peters thinks that, in consequence of the way in which the error of collimation is determined, errors of observation may exist with a yearly period, and that these may slightly affect the resulting value of nutation. Baily's coefficient of aberration is

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employed, the annual parallaxes of the stars are neglected, and the equations of condition are not treated by the method of least squares.

M. Busch has deduced the constant of nutation from Bradley's observations at Kew and Wansted. The reductions are made in the most strict manner, except that the annual parallaxes are neglected, and M. Peters regards the result as worthy of the highest confidence.

M. Peters then enters upon his own investigations, which are based on 603 right ascensions of *Polaris*, observed at Dorpat between 1822 and 1838, with Reichenbach and Ertel's meridian circle. Of these observations, the first 249 were made by M. Struve, and the remaining 354 by M. Preuss. These are compared with the right ascensions deduced from the *Tabulæ Regiomontanæ*, and the equations of condition thence arising are treated by the method of least squares, taking as the unknown quantities the correction of the constant of nutation, the correction of the constant of aberration, the annual parallax, the corrections for the position of the axis of the transit-circle (illuminated pivot east or west), the correction of the star's right ascension, and the personal equation of the two observers.

The equations are first solved, giving equal weight to all the observations. The observations are then divided into two groups (one for each observer), and the equations of each group are solved separately. There is a surprising agreement between the results found from the four years' observations of M. Struve, and the twelve years' observations of M. Preuss, the coefficients of nutation deduced differing by less than three-hundredths of a second. This investigation supplies a measure of the precision of the separate observations, and it is found that M. Struve's observations are entitled to greater weight than those of M. Preuss.

The whole of the observations are then combined, giving the proper relative weights just obtained, and the equations are re-solved. The values found for the unknown quantities differ extremely little from the results given by the supposition of equal weights.

One of the most striking results is the constant difference between the right ascension given by the two observers, or the personal equation, which amounts, for *Polaris*, to more than 0·8 of a second of time. The magnitude of this shows that the personal equation changes with the declination of the stars. Hence, also, we may easily understand that M. Lindenau's results may be vitiated by the omission of the consideration of personal equation, especially as the observations which he employed were made with different instruments, as well as by different observers.

While M. Peters was employed in these investigations, M. Lundahl was likewise engaged in discussing the observations of declination of the same star, made also at Dorpat within the same space of time. The value of the constant of nutation which he deduces agrees admirably with those found by MM. Peters and Busch.

Finally, M. Peters takes the mean of the three results, giving

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the proper relative weights to the several determinations, and he finds the most probable value of the constant to be $9''\cdot2231$ with the probable error $0''\cdot0154$. This value differs very little from Brinkley's, which has generally been employed by English astronomers, but M. Peters' determination undoubtedly possesses much greater weight.

M. Peters next enters upon a theoretical investigation of nutation, far more complete than any that had before appeared. Starting from the equations of Poisson's theory, he developes them, taking into account the ellipticities of the orbits of the earth and moon, and also the principal lunar inequalities. He thus obtains a great number of small terms which had previously been neglected. Most of these may be safely omitted; but there are two terms which should be taken into account in delicate investigations, as they have an annual period, and are therefore mixed up with the effect of aberration and parallax. M. Peters takes care to apply the requisite corrections to the coefficients of aberration, and to the parallax of *Polaris* given by his investigations. Although most of the new terms found by M. Peters are very small, yet these researches are not the less valuable, since it is always satisfactory to know what we really neglect.

M. Peters takes into account the effect of a possible difference between the ellipticities of the two hemispheres, which he determines by means of the pendulum experiments collected by Mr. Baily in his "Report on the experiments made by Foster," in the seventh volume of the *Memoirs* of the Royal Astronomical Society. It fortunately happens that this effect is insensible, as this difference of the two hemispheres is extremely doubtful.

The last part of M. Peters' paper contains researches on the obliquity of the ecliptic and the precession of the equinoxes, so that he treats of all the elements which relate to the apparent changes in the places of the stars, due to the motion of the pole of the earth. He deduces the secular diminution of the obliquity of the ecliptic by comparing the obliquity for 1757, given by Bradley's observations, with that for 1825 given by the observations of Dorpat, both being reduced to the mean by the new value of nutation. The rate of the diminution so found agrees very well with that found by M. Le Verrier from theory, the difference not amounting to one second in a century. The true value of the obliquity of the ecliptic at a given epoch cannot, however, be considered as definitively settled, in consequence of the puzzling constant differences between the declinations determined at different observatories. For instance, the obliquity given by the mean of several years' observations at Greenwich exceeds by rather more than one second the obliquity for the same epoch given by M. Peters' investigations.

M. Peters' researches respecting precession are based on the results of M. Otto Struve's paper, which obtained our medal on a former occasion, combined with M. Le Verrier's determination of the secular change in the position of the ecliptic.

M. Otto Struve determines, independently, by observation, the

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values of two constants on which the precessions in right ascension and declination depend. Now, theory establishes a relation between these constants, and M. Peters is thereby enabled to find the most probable values which result from the combination of the observed values, and thence to derive complete formulæ for precession applicable to any given epoch.

I have no hesitation in regarding M. Peters' results, with respect both to precession and nutation, as definitive for the present state of astronomy.

I now come to M. Peters' second paper, which relates to the delicate subject of the parallax of the fixed stars.

The first part of this important paper contains an historical and critical review of the researches of astronomers respecting parallax from the time of Tycho to the year 1842. The second treats of the parallaxes of several stars as determined by M. Peters' own observations, made at Pulkowa by means of the great vertical circle of Ertel. In the third part, the results of the two former are applied to determine the mean parallax of stars of the second magnitude.

The historical part is drawn up with great care, and contains many curious and interesting discussions on particular points. For instance, M. Peters shows that the coefficient of aberration may be obtained with great accuracy from Flamsteed's observations of the zenith distance of the pole-star. The probable error of a single observation is found to be only 6″, which gives a far higher idea of the accuracy of Flamsteed's observations than has been generally entertained. Bradley himself remarked, that Flamsteed's observations of the pole-star agreed with his theory of aberration.

The celebrated controversy between Brinkley and Pond is discussed at considerable length, and the labours of the latter astronomer are criticised with great severity. M. Peters considers that Brinkley was far superior to his opponent in his knowledge of the theory of his instruments and in the use of precautions to avoid error, though it is certain that Pond was the more correct in his conclusions respecting parallax.

The parallaxes determined by M. Struve at Dorpat, from 1818 to 1821, by means of observed differences of right ascension of circumpolar stars having nearly opposite right ascension, deservedly occupy a good deal of attention. The parallaxes thus found, though small, were almost all positive, and M. Peters confirms their reality by the following ingenious consideration. He shows that any diurnal variation of the instrument due to temperature will affect the coefficients of aberration and parallax in the same direction, and the former probably more than the latter. Now, the coefficient of aberration found from these observations is about 0″·08 less than the definitive value given by the Pulkowa observations, and it is therefore probable that M. Struve's parallaxes should be increased by a few hundredths of a second.

It is unnecessary for me to follow M. Peters in his account of Struve's micrometrical measurements of the parallax of *α Lyræ*, of Bessel's well-known observations of 61 *Cygni* with the heliometer,

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and of the parallaxes of *α Centauri* and *Sirius*, as determined by MM. Henderson and Maclear at the Cape, as these have been fully discussed by Mr. Main in an able paper in the twelfth volume of our *Memoirs*. The Council is also indebted to Mr. Main for a careful report on M. Peters' paper, from which I have derived considerable assistance in drawing up my account of it.

The second, and most important, part of M. Peters' paper consists of an investigation of the parallaxes of eight stars, by means of observations of zenith distance made by M. Peters at Pulkowa, in 1842 and 1843, with Ertel's great vertical circle. The stars selected are *Polaris*, *Capella*, *ι Ursæ Majoris*, *Groombridge* 1830, *Arcturus*, *α Lyræ*, *α Cygni*, and 61 *Cygni*.

The utmost care is taken in the instrumental adjustments, in the equalisation of the interior and exterior temperatures, and in eliminating every imaginable source of error.

It would be impossible for me to convey an adequate idea to any one unacquainted with M. Peters' paper, of the numerous precautions used by him for this purpose. For instance, the observations are made by placing the wire very near the star and then waiting for the time when the star is exactly bisected by it. The large motions of the instrument are always made without touching either the telescope, or the divided circle, or the pieces carrying the microscopes. In making the double observation (face East and face West) the micrometer-screw is always turned finally in the same direction, the reading of the levels is always commenced at the same end of the scale (though they are protected from heat by glasses). The effect of flexure of the telescope-tube is eliminated by an important arrangement, by which the eye-piece and object-glass are capable of being fixed at pleasure at either end of the tube. This transposition was made after every eight complete observations of the sun.

At every observation the readings of the microscopes are taken for coincidence with both the preceding and succeeding divisions on the limb, and the utmost pains are employed to correct for any inequality in the micrometer-screw and for errors of division.

Again, in the reduction of the observations and the elimination of the unknown quantities, the same attention to minute accuracy is observable. Thus, small terms are introduced into the expressions for aberration and nutation which had hitherto been neglected, and an elaborate investigation is entered into respecting the proper motions of the stars observed. The unknown quantities to be determined are the correction to the assumed latitude, the flexure of the telescope tube, the correction of the thermometrical coefficient of refraction, the correction of the assumed mean declination, the annual parallax, and the correction of the coefficient of aberration. Of these, the first three are found by means of the observations of the pole-star. All the equations are solved by the method of least squares, and the greatest care is used in estimating the probable errors of all the results, whether arising from probable errors of observation or uncertainty in the elements employed in the calculation.

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There are also discussions on some curious points, such as the effect of clouds on refraction, the possible variability of latitude, &c. The resulting values for parallax are all positive, with the exception of that of *α Cygni*, which comes out a minute negative quantity; this, of course, only indicates that the real parallax of that star is probably extremely small.

The constant of aberration obtained by taking the mean of the several results for the different stars is 20″·481, which differs only 0″·036 from the definitive value found by M. Struve. The smallness of this difference gives great confidence as to the accuracy of the results for parallax, as there is no reason why the aberration should be found more accurately than the parallax.

Another strong confirmation is afforded by the fact, that the parallax of 61 *Cygni* determined by M. Peters is absolutely identical with that found by Bessel by means of the heliometer.

The last part of M. Peters' paper treats of the mean value of the parallax of stars of the second magnitude. M. Peters finds that there are thirty-five stars whose parallaxes are determined with sufficient accuracy to serve as a basis in this research. Of these, however, he excludes two stars which have very large proper motions, 61 *Cygni* and 1830 *Groombridge*, as exceptional, and therefore not properly to be included when an average is the quantity sought. Struve's scale of relative distances of stars of different magnitudes is employed in combining the observed parallaxes for different stars, although the final result is nearly independent of the assumed scale, inasmuch as the second magnitude is nearly the mean of all the magnitudes of the stars employed.

M. Peters shows his usual skill in estimating the probable errors which may arise from the defects of the hypotheses employed, such as that of the same absolute brightness of the stars, as well as from the errors of the observed parallaxes; and he finally arrives at the result, that the most probable value of the mean parallax of stars of the second magnitude is 0″·116, and that the probable error of this determination is only 0″·014.

M. Peters closes his paper with a most interesting result deduced by combining his own researches with those of M. Otto Struve respecting the solar motion. M. Otto Struve finds that the annual apparent motion of the sun, as seen at right angles from a point at the mean distance of stars of the first magnitude, is 0″·339. Now, according to M. Peters, the mean parallax of a star of the first magnitude is 0″·209; so that we are able to turn the former result into absolute measure. Thus the annual motion of the sun with respect to the great body of the surrounding stars is equal to 1·623 times the radius of the earth's orbit.

I cannot but regard this work of M. Peters as a perfect model of excellence, evincing consummate skill in the observer, as well as admirable power of turning the observations to the best account. It shows that it is possible by meridional observations to obtain absolute parallaxes almost as small as the relative parallaxes that can be measured by the heliometer or by similar means; though to do

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so requires a most rare union of instrumental advantages, care and judgment in the observer, and analytical skill in combining in the best manner the results of observation.

No one can read the papers of M. Peters, or those of the Russian and German astronomers generally, without being struck with the constant employment of the method of least squares. It is to be wished that this method were more in use among English astronomers, as I believe not a little of the precision of modern determinations is due to it. We seem to entertain a distrust respecting the results of the calculus of probabilities, more particularly with regard to the estimation which it affords of the probable amount of error in any determination.

It should be borne in mind, that when we speak of the probable error being of a certain amount, it is not meant that it is improbable that the error should exceed that amount, but only that it is as probable *à priori* that the error falls short of, as that it exceeds it. If we know by independent means that the error of any determination is much greater than the probable error given by the observations, we may infer, with great probability, that some constant cause of error has occurred in the observations employed. In the estimation of probable error, only fortuitous causes of error are taken into account. The employment of the method of least squares does not render it less necessary to avoid all sources of constant error: it is not a substitute for, but an auxiliary to good observations, and enables us to obtain from them all that they are capable of yielding.

I cannot conclude without congratulating the Society on the improved prospects of that very delicate branch of astronomy which relates to the research of stellar parallax, especially as there is every reason to believe that this country will contribute its full share to the advancement of it. We may hope that the beautiful reflex zenith telescope of the Astronomer Royal, the magnificent heliometer which is in the able hands of Mr. Johnson, and the improved method of recording star transits by means of galvanism, will enable us ere long to take many firm, though long-reaching, steps into regions of space hitherto untrodden.

(*The President then, delivering the Medal to Mr. Hind, Foreign Secretary, addressed him in the following terms*):—

In transmitting this medal to M. Peters, you will assure him of our high appreciation of the importance of the results at which he has arrived, and of the admirable science and skill which he has shown in obtaining them; and you will express our confident hope that in his new sphere at Konigsberg, he will confirm and add to the reputation which he has so deservedly acquired at the observatory of Pulkowa.